THE LOVEJOY FORMATION OF NORTHERN CALIFORNIA

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ABSTRACT

Basalt lavas of Tertiary age in Plumas, Butte, Tehama, and Solano counties, and beneath the Sacramento Valley both north and south of Sutter Buttes, have been previously assigned tentatively to various ages, mostly Pliocene.

The principal occurrences extending from near Honey Lake in Lassen County to Orland Buttes in Tehama County and to Putnam Peak, near Vacaville in Solano County, have been studied in the field and a large collection of samples have been examined microscopically. Cuttings from three wells in the Sacramento Valley have also been studied.

The megascopic aspects of the basalts at all occurrences are virtually identical. Microscopically the rocks are distinctive, in respect to the nature of a mesostasis, which is of two principal types and seven subtypes. Most of the subtypes are found at all principal occurrences.

It is concluded that all described occurrences of these rocks are parts of a once continuous sheet of lava called the Lovejoy formation. It is suggested, as a hypothesis, that the lavas were erupted east of the Honey Lake fault scarp and that magma flowed southwest through a broad valley to the Sacramento Valley.

The age of the Lovejoy formation is established as Upper Eocene or Lower Oligocene, based on its stratigraphic position, and the occurrence of Lovejoy basalt reworked into beds below the Upper Eocene or Lower Oligocene tuff at La Porte, Plumas County, California.

INTRODUCTION

THE LOVEJOY formation was named for Lovejoy Creek adjacent to a principal occurrence of the formation on the north side of Little Grizzly Creek, in sec. 8, T.24N., R.12E. Blairsden quadrangle, Plumas County, California (Durrell, 1959).

The formation consists principally of lava flows of basalt that now occur here and there in a southwest-trending strip across the Blairsden quadrangle. The strip continues both to the northeast and southwest, and is evident on the geologic maps of the Downieville and Bidwell Bar quadrangles (Turner, 1897, 1898).

The present paper is concerned with the extent and age of the Lovejoy formation, for rocks elsewhere in the region that are identical with those in the Blairsden quadrangle have been assigned to diverse ages. This paper, which began to develop in 1955, is the outgrowth of long continued work on the geology of the Blairsden quadrangle.

I am grateful to the Committee on Research of the University of California, Los Angeles, for financial support. Too, I wish to acknowledge assistance from the Humble Oil & Refining Company for well cuttings, supplied by John Frick and Andrew Marianos, and, from the General Petroleum Corporation for information on the distribution of the basalt under the Sacramento Valley, supplied by Robert Orwig and C. W. Cline.

HISTORICAL REVIEW

Downieville and Bidwell Bar Quadrangles

The basalts assigned to the Lovejoy formation were described by H. W. Turner in a series of papers (Turner, 1895, 1896, 1899, 1898) in which he called the rocks the "older basalt" in contradistinction to a much younger basalt that he variously called late basalt, dolerite, and olivine basalt. He made particular mention of an area along Red Clover Creek in the northeastern part of the Downieville quadrangle (1897), which is also in the northeastern part of the Blairsden quadrangle and is designated as the type area of the Lovejoy formation (Durrell, 1959). He also mentioned occurrences along Onion Valley Creek, on Mooreville Ridge, at Walker Plain, Oroville Table Mountain, Kanaka Peak, and the Iron Canyon of Chico Creek. He left no doubt that he thought the basalt at all of these places was the same.

He clearly recognized that the older basalt is older than the andesite breccia and mentioned that this relationship was observed at Red Clover Creek, at a point 5 miles southeast of Quincy on the La Porte road, 9 miles northwest of Pilot Peak, and at several places in the vicinity of Onion Valley.

In his 1895 report he stated that the section on Red Clover Creek is 500 feet thick, and an illustration opposite page 494 shows pyroxene andesite breccia on the basalt. This is the type area and the relationship is correctly shown.

In a later report (1896), Turner repeated much from the report of 1895, and added a few facts. He mentioned (p. 543) that although the basalt is older than hornblende-pyroxene andesite, some andesitic eruptions took place before the extrusion of the basalt because there are pebbles of andesite under the basalt of Oroville Table Mountain. He mentioned that the basalt at Oroville Table Mountain rests on the Ione formation, and that the Ione must have been uplifted above water before the deposition of the basalt because of the absence of a scoria zone at the base of the basalt. Thus he implied the presence of an unconformity. This is supported by the statement, also in the earlier report, that the same basalt in Chico Creek rests on the Cretaceous sandstones. The basalt on Chico Creek is mentioned as being 200 feet thick (p. 544).

The thickness of the basalt west of Little Grass Valley (Downieville quadrangle: northeast end of Lumpkin Ridge) is given as not less than 500 feet (p. 567).

On page 614 he described the section at Red Clover Creek in much the same terms as in the report of 1895, but he gave the thickness of the basalt as 1,000 feet, an obvious error. He stated that the basalt on Red Clover Creek was believed to have been erupted from vents nearby, but no evidence is given. He also suggested that the lava about Onion Valley and along the South Fork of the Feather River, in the Bidwell Bar quadrangle (on Lumpkin and Mooreville ridges) originated near Onion Valley, but he gave no evidence.

In the Downieville Folio (no. 37), published in 1897, Turner added almost nothing to the previous description, but here he was forced to assume an age relationship between the older basalt and the rhyolite tuff. On the map legend he showed the rhyolite as the older, and in the text he described the rhyolite

first, but he stated that he had not seen the two in contact and that the relative age was not established beyond a doubt. In this area and also in the Bidwell Bar quadrangle (Turner, 1898) the basalt is shown as Neocene on the map legend.

Oroville Table Mountain

Turner's geologic maps did not extend as far west as Oroville Table Mountain although he was familiar with the region. However, W. Lindgren (1911, p. 86) published a map of that area on which he showed the basalt resting on the Ione formation.

In 1916 R. E. Dickerson published a paper that includes a section at Oroville Table Mountain; he shows 10 to 20 feet of andesite tuff breccia below the basalt which he said occurs on the south side of the mountain (p. 390).

In 1929, in his well-known monograph on the Ione formation, V. T. Allen included a map of Oroville Table Mountain, modified from that of Lindgren, in which he shows andesite tuff between the basalt and the Ione formation. Allen did not assign an age to the basalt.

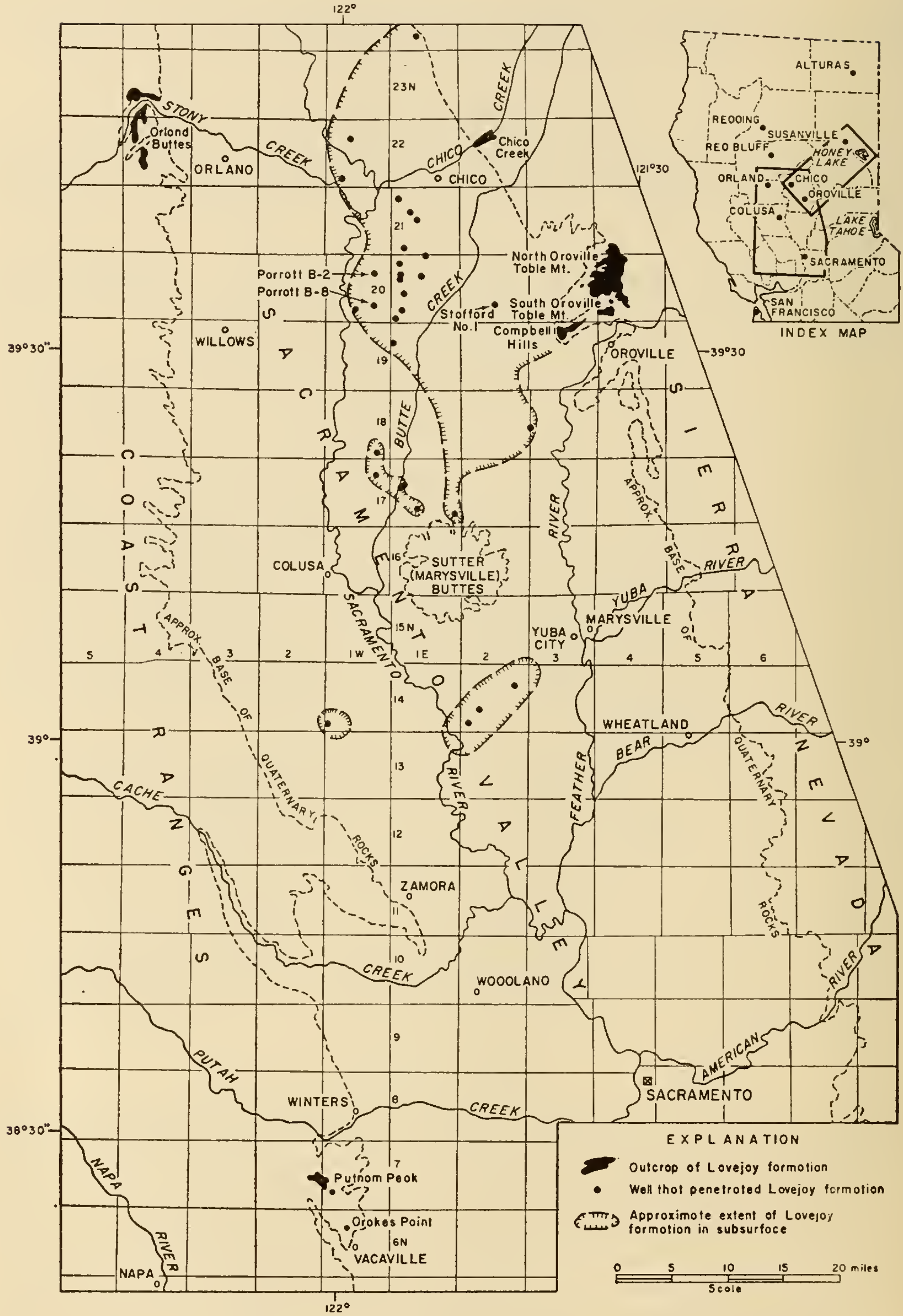
Still more recently Creely (1954) mapped Oroville Table Mountain and tentatively correlated beds beneath the basalt with the Mio-Pliocene Mehrten formation (Axelrod, 1957) of the central Sierra Nevada, and he described the Mehrten of the Oroville quadrangle generally as consisting of andesite lapilli tuff and tuff breccia. His Mehrten formation has about the same distribution as the andesite tuff on Allen's map. Neither of them shows andesite tuff on the south side of the mountain where Dickerson reported it. Both show andesite tuff on the north side of the mountain, and in the saddle between it and the Campbell Hills, and in the Campbell Hills.

Creely did not assign a definite age to the basalt, but left the question open. He said: "Thus if the andesitic rocks at Oroville, questionably referred to the Mehrten, actually belong to the later andesites, the 'older basalt' may be upper Miocene to lower Pliocene. But if the andesites at Oroville are of the earlier period of eruption (cf. Reed's Creek andesitic rocks of Clark and Anderson), the lower age limit of the basalt must be extended at least as low as the early Oligocene." (Creely, 1954, p. 187.) Since, however, he showed the andesite as Mehrten on his map, the presumption remains that he preferred the younger age.

Creely (1954, p. 187), was unable to find any source of the basalt within the Oroville quadrangle.

Orland Buttes

Basalt similar in every way to that at Oroville Table Mountain occurs on the west side of the Sacramento Valley at Orland Buttes, 7 miles west of Orland in the Fruto and Flourney quadrangles. These rocks were first, but only briefly, described by Anderson and Russell (1939). According to them the basalt at Orland Buttes (Stony Creek Buttes in their paper) is 20 to 30 feet thick, dips 5° east, rests on marine Cretaceous rocks and is overlain by the continental Tehama formation of Pliocene age. They suggest a possible intrusive origin for the basalt, but favor a surface origin. A cross section is shown on page 236, but there is no detailed map. The age of the basalt is not stated in the text, but it is shown on the small scale map as Late Tertiary or Quaternary.



Map 1. Map of the Sacramento Valley showing the Lovejoy formation in outcrop and subsurface, and an index map of northern California.

Creely (1954, p. 177) suggested that the basalt of Orland Buttes was the same age as that of Oroville Table Mountain, but thought that they could not have been erupted from the same conduit.

Putnam Peak Basalt

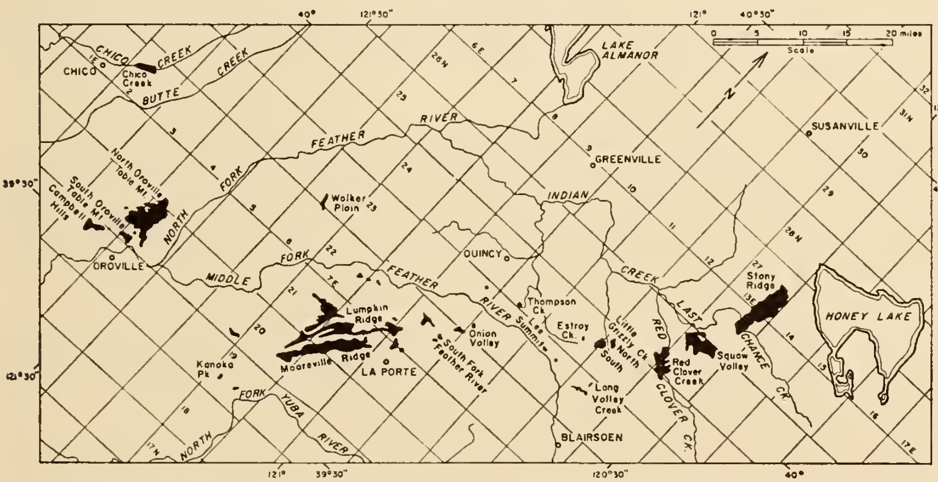
In 1949 Weaver published a monograph with extensive map coverage of a part of the Coast Ranges north of San Francisco Bay. On the Vacaville and Mount Vaca quadrangles along the west margin of the Sacramento Valley, there are several small areas and one larger area of about 1 square mile of basalt that is identical with that at Orland Buttes and at Oroville Table Mountain. Weaver called this the Putnam Peak basalt, and designated its age as Pliocene. He stated that it rests on both the Eocene Markley sandstone and the Miocene Neroly sandstone. Both megascopic and microscopic descriptions are given briefly. The thickness is stated to be 25 to about 300 feet.

Sacramento Valley

In recent years drilling operations for gas in the Sacramento Valley have shown that basalt is present extensively but not continuously in the subsurface of the Valley, both north and south of Sutter Buttes. The basalt is shown on the Sacramento Valley cross sections of the Pacific Section of the American Association of Petroleum Geologists (Cross, n.d.), as resting on the Middle Eocene Capay formation, overlain by Pliocene, and from 200 to 400 feet thick. It is considered to be Pliocene in age.

CHARACTER OF THE LOVEJOY FORMATION

The foregoing review indicates and the maps (1 and 2) show that rocks believed to belong to the Lovejoy formation extend from the northeast end of Stony Ridge at the crest of the Honey Lake fault scarp in the northwestern quarter of the Milford quadrangle to Oroville, a distance of about 75 miles, thence northwest-



Map 2. Map of the northern Sierra Nevada showing the distribution of the Lovejoy formation in outcrop. Note that map 2 overlaps map 1.

erly to Orland Buttes about 46 miles from Oroville, and southwesterly to Putnam Peak, about 78 miles from Oroville. The total direct distance from the point on the Honey Lake fault scarp to Putnam Peak is about 147 miles.

All known occurrences of rocks believed to belong to the Lovejoy formation are shown on maps 1 and 2. I have visited most of them and have collected numerous samples, most of which have been examined microscopically. Samples from three wells in the northern Sacramento Valley, supplied by the Humble Oil & Refining Company, have also been studied microscopically. A total of 112 thin sections have been studied.

The formation consists dominantly of olivine basalt lava that is distinctive both macroscopically and microscopically. Only minor amounts of sand and gravel are known to be interbedded with the lavas, and at only a few places. The distinctive Lovejoy basalt can be readily recognized when reworked into younger rocks as is the case in the Blairsden quadrangle and surrounding regions.

Megascopic Aspects of the Rocks

The Lovejoy formation generally forms terraced slopes where several flows are present; the terraces mark the interflow contacts, and the interiors of the flows form steep slopes, talus slopes, or cliffs (pl. 30, *a*). The upper surface of the formation is commonly very flat, being an exumed surface formerly covered by younger rocks. Such broad flats are shown on 15-minute topographic maps as follows: Milford quadrangle, Stony Ridge; Blairsden quadrangle, in secs. 29 and 30, T.25N., R.13E., along Red Clover Creek: Mooreville Ridge quadrangle, on Mooreville Ridge; Lumpkin Ridge, and the ridge northwest of Lumpkin Ridge, notably in the two eastern tiers of sections in E.21N., R.7E.; Oroville quadrangle on both North Table Mountain and South Table Mountain.

The flat upper surface on the Lovejoy formation develops by the removal of younger rocks, the Lovejoy being conspicuously more resistant to weathering and erosion than adjacent rocks. This is probably due partly to resistance of the rock to decay, for reasons unknown, and partly to the great abundance of joints through which surface water is conducted, instead of flowing as surface streams. Both the flat upper surface and the interflow benches are covered with fragments of basalt very much like desert pavement.

Areas of the Lovejoy formation are conspicuously lacking in vegetative cover compared to surrounding rocks, particularly on south slopes where rock in place crops out in abundance. Forest trees grow along ravines and on the interflow benches. Much of the flat area is covered with grass but, in many instances, only sparsely owing to the stony ground. On north slopes in the middle Sierra Nevada, the Lovejoy is forest covered but the ground is very stony.

Slopes below the Lovejoy are studded with great blocks of basalt that have tumbled from the cliffs above. Such blocks, 2 to 30 or more feet in diameter, hold together in spite of the close joining. In some instances such blocks have traveled by gravity for as much as a mile.

Where underlain by softer rocks, landslides are common. Talus, slides, and rolled blocks often obscure the lower contact, and slides add confusion to thickness determinations, and to counts of the number of lava flows in a section.

Some of the flows form conspicuous black cliffs, such as that about the North and South Table mountains of Oroville which range up to 200 feet in height, Generally such cliffs are only 10 to 50 feet in height and extend through but a single flow.

The jointing of the basalt, well displayed in cliffs but obvious in all outcrops is a characteristic feature of the rock, and can be seen at all areas of occurrence (pl. 30, *b*). The jointing is primarily columnar, with columns mostly 3 to 12 inches in diameter. The columns are very irregular, however, with nonplanar sides that curve and twist in a most peculiar way. The joints that bound the columns are discontinuous in that respect, and pass into and out of the columns.

Other joints divide the columns into blocks that generally range from 3 to 10 inches in maximum dimension. The joint blocks are roughly equidimensional, have many reëntrant angles and often show conchoidal surfaces. Even within these blocks there are inconspicuous joints that open with a light tap of the hammer. It is, consequently, very difficult to obtain clean and trimmed specimens. Freshly broken surfaces are dull black, irregular, and often conchoidal. At a few places, this characteristic joint pattern fails, and more regular columns of larger size are present, or, larger and more regular joint blocks are present. Such a flow is that which crops out between the 600- and 650-foot contours on the west end of South Oroville Table Mountain, and forms a narrow flat there. This is in the southeast and northeast quarters of sec. 36, and is best located on the Oroville 7½-minute quadrangle.

Many flows show little or no vesicularity, while others are highly vesicular. The vesicles range from 2 inches in diameter to microscopic. Rarely are they flattened; mostly they are remarkably spherical, even where closely spaced. Scoria has not been seen, and no scoriaceous zones occur between the flows; in fact, it is nearly impossible to find the surface of contact of adjacent flows.

About a third of the flows show some fluidal structure, mostly evidenced by a sheen on surfaces parallel to the base of the flow owing to the alignment of the 010 faces of the plagioclase microlites. On weathered surfaces there is often a fine streaking parallel to the base of the flow. A joint system parallel to the flow planes is present in a few instances. Vesicles when flattened have their larger dimensions on the flow planes.

The color of the freshly broken lava is in most instances black, and the intensity of black seems to be related to the state of aggregation of magnetite: those flows with the coarsest magnetite are gray. The weathering colors are gray and brown, and both develop from the same rock, the brown color resulting from more advanced decay. Stony surfaces over the basalt are brown and the soil is chocolate brown.

Most of the basalt is dense and uniform in the hand specimen, but some flows contain scattered phenocrysts of olivine or plagioclase or both. At Lee Summit and at Red Clover Creek the uppermost flow at each place contains conspicuous plagioclase phenocrysts in clusters of three to six or more crystals. The two flows that comprise the section east of Little Long Valley Creek contain abundant thin tabular phenocrysts as much as 10 mm. in diameter, perfectly aligned by flow.

Of the megascopic features described above, the following are most charac-

teristic, and are present at all occurrences: cliff-forming character of the intensely jointed flows, large rolled blocks of the jointed lava and well-developed talus, stony ground and scarcity of vegetation, irregular joint pattern and crude columnar structure, general scarcity of vesicles, and absence of scoria zones between flows, dense-black color of the fresh lava and brown color of the weathered lava.

Microscopic Aspects of the Rocks

In thin sections it is seen that some of the rocks are porphyritic, and that some are not. Phenocrysts when present are set in a groundmass of euhedral plagioclase laths between which are grains of olivine, augite, and magnetite. A finer mesostasis occupies the remaining space. Thus the rocks are composed of three entities if porphyritic, or two if they are not: phenocrysts, groundmass, and mesostasis. This discussion is based only on surface samples, and not upon the well sections, since only cuttings were available and samples could not be counted.

The greater part of all the rocks consists of euhedral lath-shaped microlites of twinned plagioclase, of intermediate composition as judged from relief. They range in size from about 0.01 mm. to 0.5 mm. and are mostly in the range of from 0.1 to 0.3 mm. Many rocks contain microphenocrysts of plagioclase only 2 or 3 times larger than the microlites. In most rocks the microlites are unoriented, but in some they are in trachytic arrangement owing to flow. The feldspar microlites touch each other so as to form a continuous lattice. There is nothing distinctive about the feldspar, and no noteworthy variations among samples.

Between the feldspar microlites are grains of colorless augite, equidimensional to slightly elongate, generally subhedral but rarely euhedral. Phenocrysts of augite have been found in only one section. A few grains are twinned, and dispersion of the extinction position can sometimes be seen. Otherwise it is very difficult to distinguish augite from olivine. The augite grains are much smaller than the plagioclase, and are generally of the order of 0.05 mm. in length.

Colorless grains of olivine occur with the augite. They are mostly euhedral, which helps in distinguishing them from augite. Olivine is much less abundant than augite. It also occurs frequently as euhedral microphenocrysts with a diameter ranging from 0.2 to 0.6 mm. Magnetite occurs as scarce to very abundant euhedral grains, from 0.01 to 0.5 mm. in diameter. The grains in each rock are quite uniform in size.

A distinctive feature of most of the rocks is a peculiar clustering of augite and olivine microlites into groups of 5 to 50 grains. Between such clusters grains of these minerals are scarce or absent, the spaces between the feldspars being occupied by magnetite grains and the mesostasis. The magnetite grains are not clustered.

In rocks in which the clustering does not occur the olivine and augite grains are uniformly distributed.

Ophitic augite has been found in a few cuttings only from one well section.

The mesostasis of the rocks is quite variable, and shows some distinctive characteristics. A minor part of the mesostasis in most of the samples consists of a chloritic substance, possibly chlorophaeite, which has three habits. It is present lining cavities, thereby forming microscopic amygdules. It occurs in patches

among the feldspar laths, of the shape and size such as would be occupied by an ophitic pyroxene, and in this occurrence it is perhaps an alteration product of glass, although unaltered glass is sometimes present next to it. It also occurs less commonly as an alteration product of olivine. This substance is always birefringent though weakly so in many instances. It is green, yellow, orange, or brown in color. Some has evidently altered to deep brownish-red goethite.

Glass occurs in the mesostatis of about one-third of the surface samples. It is clear and varies in color from colorless to deep brown. Much of the glass is turbid with opaque dust that is probably magnetite. There seems to be a roughly inverse relationship between the amount of glass and opaque dust, there being more dust in the glass in those rocks with the least glass.

A colorless mineral, probably apatite, occurs in the glass in those rocks in which glass constitutes most of the mesostasis. The grains are needlelike, with negative elongation and straight extinction, and with relief, fracture, and surface characteristics like apatite. The needles are exceedingly slender, and usually not more than 0.1 mm. long, though some as much as 0.5 mm. long have been found.

A pale lilac-colored mineral, probably augite, of needlelike habit, often in radial bundles, constitutes most of the mesostasis in most of the samples. This mineral has extinction at 45° to the elongation, has positive elongation in straight extinguishing sections, and a positive optic angle of about 60°. It has relief appropriate to augite, and in some instances can be seen to be continuous with the colorless augite grains of the groundmass. It is highly probable that it is a slightly titaniferous monoclinic pyroxene.

In some rocks this augite is exceedingly fine grained, and is obscured by quantities of magnetite dust so that it can be observed only in extra-thin sections. In others it is clear and easily visible. It is usually associated with large amounts of magnetite dust or featherlike or arborescent growths of magnetite. It is only infrequently associated with glass or with apatite.

Magnetite of the mesotasis occurs in three modes, as crystals of smaller size than those of the groundmass, as dust in glass or with augite, and as arborescent or featherlike growths that are associated only with augite of the mesostasis.

Thus there are measures of uniformity and of variation among these rocks. Features common to all are the habit of intermediate composition of the feldspar, the textural position, habit, and relative abundance of the groundmass olivine, and augite, and the rather uniform grain size. Variability is evident with respect to the mesostasis, the last liquid fraction to consolidate.

Nothing significant appears from a consideration of the presence or absence of the so-called chlorophaeite, or the presence or absence of phenocrysts. However, it is clear almost at a glance that the rocks fall into two groups based on the nature of the mesostasis.

In one group the mesostasis is mostly glass that contains needles of apatite. Magnetite dust is generally sparse or absent, and the groundmass augite and olivine is mostly not clustered.

In the second group the mesostasis is of the lilac-colored augite, mostly without glass, mostly with magnetite in featherlike or arborescent forms, otherwise as dust, and mostly so abundant as to make the mesostasis appear to be opaque and

black, and without apatite. In all but three of the samples the groundmass augite and olivine are clustered.

Each group has been further divided as follows:

Type 1: 27 of 73 specimens.

Type 1*a:* 8 of 27 samples.
Microlites: fine grained, not clustered, mostly oriented by flow.
Mesostasis: abundant clear glass, apatite present, magnetite in distinct crystals, mesostasis light colored.

Type 1*b:* 10 of 27 samples.
Microlites: coarser grained than 1*a*, mostly clustered, few samples oriented by flow.
Mesostasis: abundant glass, clear or clouded by magnetite dust, all magnetite as dust, apatite present, mesostasis light colored.

Type 1*c:* 9 of 27 samples.
Microlites: few samples clustered, no samples oriented by flow.
Mesostasis: relatively little glass, glass clouded with magnetite dust, magnetite all as dust, mesostasis dark colored owing to magnetite dust.

Type 2: 46 of 73 samples.

Type 2*a:* 28 of 46 samples.
Microlites: clustered in all specimens.
Mesostasis: black in sections of standard thickness, glass not present or not visible, augite needles constitute most of mesostasis, remainder is magnetite.

Type 2*b:* 10 of 46 samples (formerly 2*c*).
Microlites: some samples not clustered, finer grained than in 2*a*.
Mesostasis: like 2*a*, but some brown glass present.

Type 2*c:* 4 of 46 samples.
Microlites: some samples not clustered, fine to coarse grained.
Mesostasis: dark but not black, brown glass rather abundant, some apatite present.
NOTE: Type 2*c* is transitional to type 1*c*.

Type 2*d:* 4 of 46 samples.
Microlites: coarser than other type 2 rocks, clustered.
Mesostasis: light colored, of augite needles and grains of magnetite.

The distributions of the types are discussed below.

PRINCIPAL OCCURRENCES OF THE LOVEJOY FORMATION

Red Clover Creek Area

The occurrence of Lovejoy basalt along Red Clover Creek was designated as the type area for the reason that the best known outcrops are present there in spite of the fact that the base is not exposed. The best section is that on the nose of the ridge in sec. 30, T.25N., R.13E., beginning at Red Clover Creek in the northeast corner of sec. 31 of the same township (map 3 and pl. 30, *a*). The section is clearly not faulted, and nine flows can be readily distinguished. The flows vary from 10 to 50 feet in thickness, and total 400 feet. One mile northwest, in sec. 25, the section is 500 feet thick.

The upper surface of the Lovejoy is an unconformity with respect to all younger rocks. Within a small area the formation is overlain variously in different fault blocks by the Ingalls formation (Oligocene?), Delleker formation (L. Miocene?), and the Warner basalt (Pliocene?) (map 3). Each younger formation at the

present time is being eroded from the Lovejoy so as to leave the upper surface of the latter exposed in nearly its original condition—an exceedingly flat, featureless, stony surface.

Of the nine recognizable flows, the topmost is unique in that it contains megascopically visible, nearly equidimensional feldspar phenocrysts. The other flows are all dense-black rocks but show considerable variability with respect to grain size, and correspondingly of color, brittleness, vesicularity, fluidal structures, and thickness. The three upper flows are, from the top down, types 1*c*, 1*a*, and 1*b*, the remaining flows from the top down are types 2*c*, 2*c*, 2*b*, 2*b*.

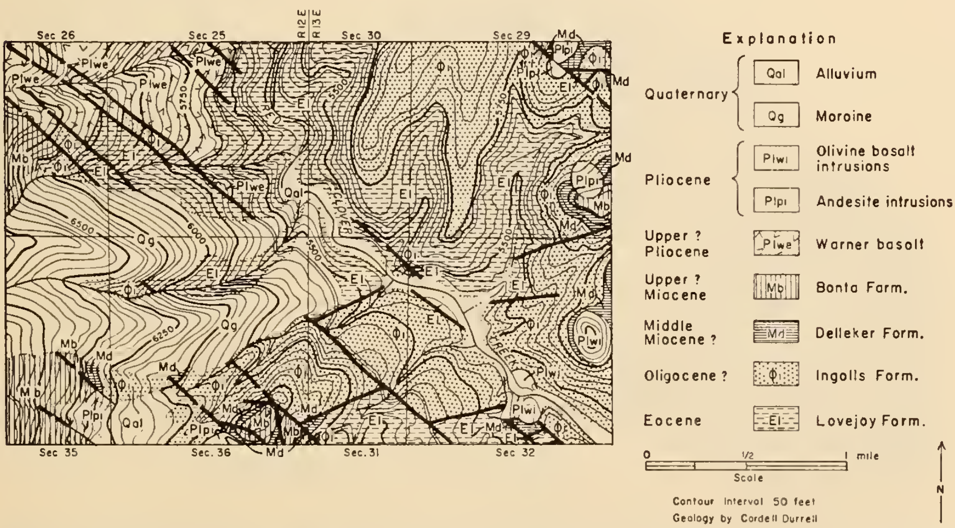
A thin sill of rather coarse olivine diabase occurs at the top of the section in the northeast quarter of sec. 29. It is not clear whether this intruded the unconformity between the Ingalls and the Lovejoy, or whether the Ingalls rests unconformably on the sill. It was once thought that the presence of the sill indicated proximity to a source of the basalt, but such is perhaps not true in view of the northeasterly extent of the basalts beyond this area. It is also possible that the sill is of the much younger Warner basalt. In any case it is unique.

Squaw Valley

The Lovejoy basalts are exposed over about 5 square miles in Lower Squaw Valley in the southern part of the Milford and Kettle Rock quadrangles. The maximum exposed thickness is about 400 feet. All aspects of the outcrops, which have been examined only casually, are the same as at the type locality described above. Two samples are of type 1*b* and 1*c*.

Stony Ridge

Stony Ridge and the ridge to the east of it in the northwestern part of the Milford quadrangle comprise an area of Lovejoy formation that is 7 by 2 miles. The flows dip gently southward, are cut off by faults at the south end, and terminate



Map 3. Geologic map of the Red Clover Creek area, Blairsden quadrangle, California, showing the type area of the Lovejoy formation, and the relation of the formation to younger formations.

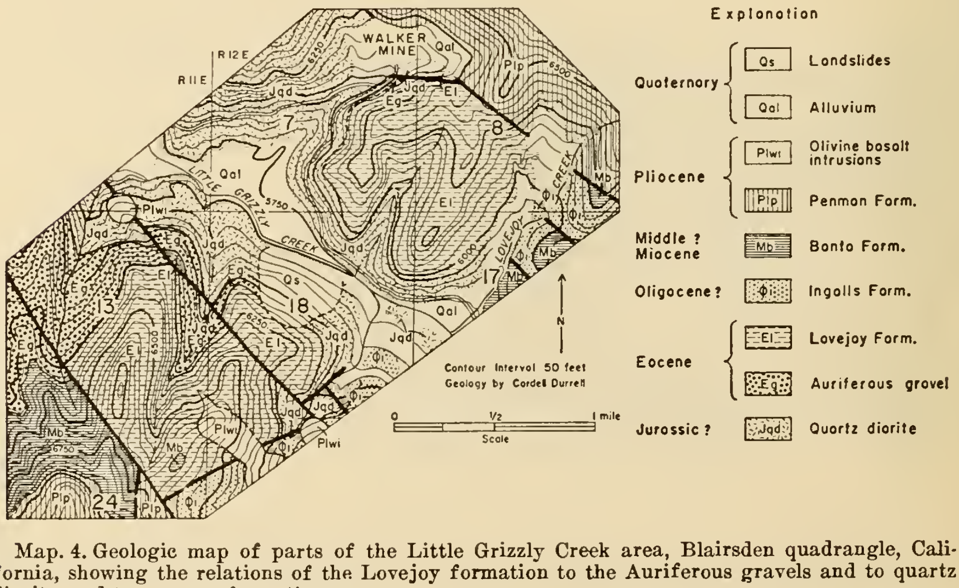
on the face of the Honey Lake fault scarp at the north end where they appear to fill a shallow valley in the underlying quartz diorite.

The section has not been studied in detail, but casual examination indicates a thickness of 600 feet. Probably there are no younger rocks on Stony Ridge. There are possibly fifteen flows in sec. 11, T.26N., R.13E., at the south end of Stony Ridge. The base is not exposed there. The rocks in all their features are identical with those at Red Clover Creek, but the porphyritic flow found at the latter place was not recognized on Stony Ridge.

Little Grizzly Creek Area

Lovejoy formation is exposed both north and south of Little Grizzly Creek in the northeastern part of the Blairsden quadrangle (map 4). On the north side of the creek between Lovejoy Creek and the Walker Mine (map 4) the areal extent of the formation is about 1 square mile. It is faulted against younger rocks on the north but the base is exposed around most of the area. The basal contact, as near as can be determined in brush and forest, is nearly flat; the relief on it must be less than 100 feet. The lowest flow rests on quartz diorite except at the northern tip of the area where a few feet of gravel are present between the quartz diorite and the basalt. The gravel is typical of the Auriferous gravels, better seen on the south side of Grizzly Creek.

At least five flows comprise the section, and range in thickness from less than 50 to more than 100 feet. Between the second and third flows from the top is a little arkosic sand with a few small pebbles. Among the talus blocks on the bench between the third and fourth flows there are very well-rounded cobbles up to 14 inches in diameter that must be coming from a gravel between the flows although the gravel is not exposed. Most of the cobbles are granitoid rocks unlike any



Map. 4. Geologic map of parts of the Little Grizzly Creek area, Blairsden quadrangle, California, showing the relations of the Lovejoy formation to the Auriferous gravels and to quartz diorite, and to younger formations.

known southeast of the Honey Lake fault scarp. They give evidence of southwestward transport. A few are of the local quartz diorite, and a few are Lovejoy basalt. Some are of hornblende andesite indistinguishable from the various hornblende andesites of the mudflows, conglomerates and fanglomerates of the younger formations of Oligocene (?), Miocene, and Pliocene ages.

The third and fifth flows each carry a few scattered phenocrysts of olivine and feldspar. Neither is the same as the topmost porphyritic flow at Red Clover Creek. In all respects, such as variability of grain size, color, fluidal structure and jointing, these rocks are megascopically identical with those on Red Clover Creek. They do not match microscopically, however, as the flows from the top down are types 1*a*, 2*b*, 2*a*, 2*a*, 2*b*.

On the south side of Little Grizzly Creek there is a little more than a square mile of Lovejoy formation in secs. 13 and 24 of T.24N., R.11E., and secs. 18 and 19 of T.24N., R.12E. (map 4). Relations are somewhat obscured by faults, talus, landslides, brush, and timber. On the west side, in sec. 13, the Lovejoy rests on the Auriferous gravels, which thickens westward, to about 350 feet in the deepest part of the underlying channel which is in Cascade Creek. Eastward the gravels thin and are overlapped in the northwest quarter of sec. 18, beyond which the Lovejoy rests on quartz diorite. As near as can be determined there is little or no relief on the base of the Lovejoy, hence it rests unconformably, as it does also on the north side of Little Grizzly Creek, on the Auriferous gravels. The section is terminated against a fault on the south.

There are probably six flows that are megascopically identical in all respects with those north of Little Grizzly Creek and with the type section on Red Clover Creek. No interbedded gravels are found here. The six samples from here are of types 1*a*, 1*c*, 2*a*, and 2*b*.

In the northeast quarter of sec. 24 a very little Bonta formation rests unconformably on the Lovejoy.

Head of Estray Creek

A mile southeast of the previously described area, in the south quarter of sec. 23, T.24N., R.11E., at the head of Estray Creek, is a small fault block of Lovejoy that is separated from metamorphic rocks by only a few cobbles of Auriferous gravels. Andesite breccia of the Penman formation rests unconformably on the Lovejoy. There are three or four flows present, all of which are typical. They have not been studied in thin section.

Lee Summit

Lee Summit, in the extreme southeastern corner of the Spring Garden quadrangle, is the drainage divide between the Middle and North forks of the Feather River, and is crossed by the Feather River Highway (U.S. 40 Alt.). There is here a small area of Lovejoy that is porphyritic with feldspar phenocrysts and is megascopically identical with the topmost flow of the type section on Red Clover Creek 12 miles to the northeast. Two samples from this area are types 1*c* and 2*a*. The Lovejoy here is overlain unconformably by Bonta formation and rests on Auriferous gravels.

Long Valley Creek Area

On the ridge west of Long Valley Creek, in secs. 8, 9, 16, 17, and 18 of T.23N., R.12E., near the center of the Blairsden quadrangle, is a 200-foot-thick section of two basalt flows believed to be Lovejoy. These rocks, however, are unlike any other Lovejoy flows in that they contain abundant 5-to-10-mm.-long, but very thin, tabular plagioclase phenocrysts perfectly aligned by flow. Megascopically the rocks are otherwise like the flows of the type Lovejoy, but microscopically they differ from all others. They occupy the same stratigraphic position by resting on Auriferous gravels, and being overlain by the Ingalls formation.

Thompson Creek Area

A small area of Lovejoy occurs near the head of Thompson Creek in sec. 33, T.24N., R.10E., in the southwestern part of the Spring Garden quadrangle. It is typical Lovejoy but only a thin section is exposed. Two samples from this area are of type 2*b*. A sample from a small occurrence nearby on the Fells Bar road is of type 1*a*.

Willow Creek Area and Vicinity

An area of "older basalt" is shown by Turner on the Downieville quadrangle map east of Willow Creek and the Quincy–La Porte road, and on a ridge just north of the Middle Fork of the Feather River (Turner, 1897). This area, more than 2 miles long, in secs. 2, 3, and 4 of T.23N., R.10E., Spring Garden quadrangle, is not the "older basalt," or Lovejoy formation, but is the "late basalt," or Warner basalt.

Another small area shown on the Downieville quadrangle as 2¼ miles west and a little south of the west end of the last-mentioned area, is likewise not "older basalt," as shown, but is a plug of Warner basalt. This plug is on Bachs Creek Ridge, at the northwest corner sec. 7, T.23N., R.10E., Quincy quadrangle.

Another area on Crescent Hill in sec. 11, T.23N., R10E., Onion Valley quadrangle, could not be reached. It may also be a plug of Warner basalt.

Onion Valley

Of the several areas of "older basalt" shown on the Downieville quadrangle in the vicinity of Onion Valley only the ones in sec. 31, T.23N., R.10E., and sec. 36, T.23N., R.9E., on the north side of Onion Valley Creek, were visited (see Onion Valley quadrangle).

In sec. 36, and extending into secs. 1 and 2 to the south, is a well-exposed section of seven flows of Lovejoy basalt that total 600 feet in thickness. The basalt is underlain by serpentine, and successive flows overlap each other to the south as though abutting the wall of a rather steep valley. The uppermost flow spreads more widely as though it topped the valley rim. The geologic relations are obscure, but the valley occupied by the lavas seems also to be present on the south side of Onion Valley Creek in secs. 9 and 10, T.22N., R.9E., Onion Valley quadrangle.

The rocks of the section are typical Lovejoy basalts in all respects. The uppermost two flows are porphyritic with equidimensional phenocrysts of plagioclase, and are megascopically similar to the uppermost porphyritic flows at Lee Summit

and at Red Clover Creek. However, the uppermost flow is type 2*a*, and the next below is type 1*c*, whereas the porphyritic flows at Red Clover Creek and Lee Summit are both type 1*c*. The remaining five flows from top down are types 2*a*, 2*a*, 1*c*, 2*a*, and 2*b*.

Headwaters of South Fork of Feather River

Two small areas in secs. 11, 12, 13, and 14, T.22N., R9E., could not be reached, but float in the South Fork of the Feather River, about 2 miles downstream, was collected. The rocks are all typical Lovejoy basalts. Of six samples collected because they looked somewhat different from each other, there is one each of types 1*a*, 1*c*, and 2*b*, and two of type 1*b*.

Lumpkin Ridge and Vicinity

The Lovejoy formation of Mooreville and Lumpkin ridges and vicinity is well shown on the southeastern part of the Bidwell Bar quadrangle (Turner, 1898). It extends eastward into the Downieville quadrangle (Turner, 1897) in the vicinity of Little Grass Valley. These areas are shown on the new La Porte, 1:24,000, and Mooreville Ridge, 1:62,500, quadrangles.

The rocks of this area extend in two long parallel southwest-trending ridges for 15 miles, one on each side of the South Fork of the Feather River. North of Lumpkin Ridge and south of Fall River there is another area of about 7 square miles. The Lovejoy basalts rest on "Auriferous gravels" at a number of places, but mostly lie on granitoid and metamorphic rocks. In the northwest, they are overlain by hornblende andesite mud flow breccias probably equivalent to the Penman formation of the Blairsden quadrangle, and, in sec. 25, T.22N., R.8E., by Warner basalt.

The Lovejoy rocks were examined at the northeast end of Lumpkin Ridge, where they are about 400 feet thick, are not very well exposed, but show all the typical features. Samples were collected from three flows, but the total number of flows is not known.

Good exposures of five flows in the upper part of the section were found along the road on Lumpkin Ridge in sec. 30, T.21N., R.8E., where the thickness of section is probably about 400 feet.

Between the third and fourth flows below the top of the ridge, exposed by the road cut at about the west line of sec. 30, is about 10 feet of gravel, mostly of rounded cobbles of Lovejoy basalt, but including some granitoid and metamorphic rocks, and a few of hornblende andesite indistinguishable from some of the hornblende andesites of the younger Tertiary formations.

The lower flows of the section were examined in sec. 11, T.20N., R.7E. The highest flow sampled is type 1*b*, and successively lower flows are types 2*c*, 2*b*, and 2*a*.

The "older basalt" is shown by Turner (1898) as a number of smaller areas scattered over the Bidwell Bar quadrangle. It is present on the ridge south of the Middle Fork of the Feather River in the east-central part of the quadrangle; at a point on the ridge 3 miles east of Bucks Ranch (now Bucks Lake) and at another point 2 miles southwest of Bucks Ranch, in the northeastern part of the

quadrangle, at the Walker Plain 5 miles northwest of the center of the quadrangle, and at Fields Ranch (now Fields Ridge), and Kanaka Peak in the south-central part of the quadrangle.

Of these minor areas, only Walker Plain has been visited. There two or three flows of typical Lovejoy basalt reach a total thickness of about 200 feet. A sample from the upper flow is type 2*a*.

Oroville Table Mountain

Oroville Table Mountain is just north of the city of Oroville, and west of the southern edge of the Bidwell Bar quadrangle. It is in the old Chico quadrangle, but is best shown on the Oroville quadrangle, 1:62,500, 1944, and on the Cherokee and Oroville quadrangles, 1:24,000, 1949. The basalt is exposed over about 12 square miles mostly on the North Table Mountain. The critical relations, however, occur about South Table Mountain and between it and the Campbell Hills. The 11 miles between Kanaka Peak, in the Bidwell Bar quadrangle, and Oroville Table Mountain is the largest gap in the chain of occurrences of Lovejoy formation thus far described.

At the west end of South Table Mountain, in the northeast quarter of sec. 36, T.20N., R.3E., the basalt section is not less than 300 feet thick and is composed of five and possibly of eight lava flows. The lower part of the section may be repeated to the west by a fault that strikes N. 7° E., and that crosses the ridge near the center of sec. 36 just east of the power line (see Oroville 1:24,000 quad.), but the relationships are obscure.

The basalt rests on anauxite-bearing sands of the Ione formation which are exposed in ravines on both the north and south sides of the ridge through the center of sec. 36. The contact east of the probable fault mentioned above is at an altitude of about 535 feet. Above the 475-foot contour the Ione is a conglomerate with very well-rounded pebbles and cobbles up to 10 inches in diameter partly of granitoid and metamorphic rocks, but a little less than one-third of the cobbles in the uppermost layers are of unmetamorphosed hornblende andesites and rhyolites. These are the andesite cobbles referred to by Turner (1896, p. 543), and evidently what was called andesite tuff by Allen (1929), andesite tuff breccia by Dickerson (1916), and Mehrten formation by Creely (1954). Certainly no andesite tuff or tuff breccia is present either on the south side of the mountain, or on the ridge at the center of sec. 36. Exposures are poor on the north side of the mountain, where Allen, Dickerson, and Creely all show andesite tuff or Mehrten formation. The same well-rounded cobbles as just described can be traced along the hillside in spite of landslides and rolled blocks of basalt and basalt talus. The only exposure found is in the ravine at the north center of sec. 36. There some 50 feet of anauxite-bearing sand is interbedded with sandy conglomerate and conglomerate is exposed not far below the base of the basalt. As on the nose of the ridge, the cobbles are very well rounded, are mostly granitoid and metamorphic rocks, but among them are plentiful unmetamorphosed hornblende andesite. There is no evidence of andesite tuff, tuff breccia, or mudflow breccia that would warrant a correlation with the Mehrten or with any of the andesitic units farther east.

The Ione formation evidently grades eastward beneath South Table Mountain into Auriferous gravels as shown by Allen (1929, p. 367, map), and by Creely (1954). Allen and Creely show andesite tuff and Mehrten formation, respectively, in the saddle between South Table Mountain and its outlier in the northwest quarter of sec. 29, T.20N., R.4E., a hill with a summit elevation of 1,095 feet. An excellent section is exposed in the ravine leading to this saddle from Morris Ravine on the east. At the level of the road, at elevation 600 feet, there are well exposed quartz-rich gravels, typical of the higher or bench gravels of the Auriferous gravel channels, interbedded with white anauxite-bearing sands and clays. Higher up the hill the gravels become coarser and more heterogeneous. Brown and red clays alternate with gravel beds. Hornblende andesite appears among the pebbles higher up and in the saddle. They, like the dominant metamorphic and granitoid rocks, are very well rounded. There is no evidence of any tuff, tuff-breccia, or mudflow breccia. This section is obviously a more conglomeratic equivalent of the Ione formation farther west, and is in total properly a part of the Auriferous gravel.

For comparison, Creely shows some Mehrten formation in the northwest quarter of sec. 9, T.19N., R.4E., on the eastern edge of the city of Oroville (this is the hill marked with elevation 419 feet just north of the west quarter corner of sec. 9). Here there is exposed a thin section of a hornblende andesite mudflow breccia resting on a conglomerate of andesite cobbles in a matrix of andesitic tuffaceous sand. There is only a little quartz in the sand, only a few quartz pebbles, and metamorphic and granitoid rocks are rare. This rock does not in any way resemble the gravels beneath Oroville Table Mountain and it does resemble the Mehrten formation, the Penman and Bonta formations of the Blairsden quadrangle, and the Reeds Creek andesite of Clark and Anderson (1938).

It is concluded that the basalt of Oroville Table Mountain rests on the Ione formation and on Auriferous gravels, and there is no intervening andesite tuff, tuff breccia, or mudflow breccia that can be correlated with any such unit elsewhere in the Sierra Nevada.

The lava flows of South Oroville Table Mountain are megascopically identical in their properties with those of the type Lovejoy. The uppermost cliff-forming flows, two or three in number and totaling 150 feet in thickness, are black, fine-grained, dense rocks that weather to a dark-brown color. The upper surface is the typical stony plain. The uppermost flows have the characteristic columnar and irregular joint pattern so typical of the Lovejoy basalts everywhere. The highest flow is type 2*a*. The third and fourth flows yield somewhat larger blocks and are types 1*c* and 2*d*, respectively. The fourth flow is grayer in color, having a coarser grain size. The fifth flow, which is type 2*d*, is flow banded, with close joints parallel to the flow structure and with more regular columns up to 2 feet in diameter. The sixth flow is fine grained, very black in color, has the typical blocky fracture pattern, and contains a few phenocrysts of olivine and feldspar. It is type 2*a*. The possible seventh and eighth flows are types 1*b* and 2*d*, respectively, but they may represent a repetition of the third and fourth flows.

Orland Buttes

At Orland Buttes (formerly Stony Buttes) 7 miles northwest of Orland on the

west margin of the Sacramento Valley, black basalts occur essentially as described by Anderson and Russell (1939, p. 236). The lavas dip gently to the east, they rest unconformably on sediments of Cretaceous age, and are overlain by the Tehama formation of Pliocene age. The geological relationships are somewhat complicated by faulting, by landslides, by talus, and by blocks of basalt that have rolled far down the slopes.

The cliff of basalt on the south tip of Black Butte, in the northeast quarter of sec. 31, T.23N., R.4W., probably the best exposed section, is estimated to be 75 feet high. Talus below the cliff conceals the base of the flow. Larger joint blocks of a coarser-grained and grayer basalt among the talus blocks indicate the presence of a second flow, also concealed by talus from the cliff above. The section on Black Butte is possibly 150 feet thick.

The upper, cliff-forming flow is typical Lovejoy basalt, with crude columns and irregular fracture. The black, brittle rock weathers brown and forms stony tablelands like the Lovejoy. It is type 2*a*. The lower coarser flow is similar to flows at Oroville Table Mountain, Lumpkin Ridge, and Red Clover Creek, and is type 1*b*.

That the Tehama formation rests unconformably on the basalt near but east of Orland Buttes is indicated by core holes that passed from Tehama into Cretaceous rocks without encountering basalt.

Putnam Peak Area

The basalt in the vicinity of Putnam Peak has all the characteristic megascopic features of the typical Lovejoy basalts. On the hill in sec. 30, T.7N., R.1W., of the Mount Vaca quadrangle, there are two flows. The upper is dense, and fine grained, very black and brittle, with the crude columnar and irregular fracture of the Lovejoy basalts. It is type 2*a*. It forms a cliff here and also in the area around Putnam Peak. Landslides, talus, and rolled blocks of the basalt obscure the contacts.

The flow below the cliff-forming one is gray, breaks into larger joint fragments, and is largely concealed by talus from the upper flow. It is type 1*b*.

According to Weaver (1949, p. 130), the basalt appears to rest, at one point, conformably on the Markley formation (Upper Eocene), but is unconformable on it because it also rests on rocks of the San Pablo group. On Weaver's maps (1949, pls. 7 and 8) the basalt is shown in two places that are so small as to be no more than blocks, which might have been carried to their present position either by rolling or sliding. At Drakes Point, a mile and a half north of Vacaville, an area of the basalt about 5 acres in extent is shown as resting partly on Markley and partly on Neroly sandstone of the San Pablo group. It seems possible, in view of the prevalence of landsliding about the margins of the basalt where it is underlain by soft rocks, that this whole body has slid eastward over the Neroly. A movement of less than 100 feet would account for the present distribution if the basalt is younger than Markley, but older than Neroly. Professor Weaver, in a recent conversation, stated that he thinks it possible that the Putnam Peak basalt is older than the Neroly.

Sacramento Valley Subsurface

Basalt has been encountered in numerous wells drilled for gas in the Sacramento Valley, both north and south of Sutter Buttes. Most, if not all, such wells are shown in map 1. The approximate extent of the basalt is largely speculative, but it is known that the sheet is discontinuous. The basalt, which is 200 to 400 feet thick, rests on rocks of Eocene age and is overlain by the Pliocene Tehama formation.

Cuttings from three wells supplied by the Humble Oil & Refining Co. through John Frick and Andrew Marianos have been examined by making thin sections of chips embedded in plastic. Twelve samples from Safford No. 1 in sec. 28, T.20N., R.2E., show that the basalt is approximately 400 feet thick. The uppermost 140 feet consists of type 2*a* basalt, all very much the same, but probably representing more than one flow.

Below this is a thin section, not more than 40 feet thick, of shale. Basalt then continues below for another 200 feet, the cuttings from which show rocks of types 1*a*, 1*b*, 1*c*, 2*a*, 2*c*, and 2*d*. In the lowest 30 feet, chips of an ophitic basalt are common, and this rock has been seen in no other place.

At least fifteen rocks are represented in the 140 feet of section below the shale, but probably there are not that many flows. There are quite surely a minimum of six flows, one of which is represented by the ophitic basalt.

Eleven samples from Parrott, B-8, in sec. 26, T.20N., R.1W., about 9 miles west of Safford No. 1, show the basalt to be a little more than 400 feet thick. As at Safford No. 1, the upper part is all type 2, but here it is at least 230 feet thick. Minor amounts of types 2*b* and 2*c* occur near the middle, and the remainder is all type 2*a*. Four rocks, and at least that many flows, are represented in this part of the section.

Below this, the next 100 feet consists of an upper part of types 1*a* and 1*b* and a lower part of types 2*a* and 2*b*. Four rocks represent at least two and possibly four flows.

The lowest two samples, which represent 40 to 50 feet of section, are dominantly of dark-brown basalt glass.

Nine samples from Parrott, B-2, about 3 miles north of Parrott, B-8, show the basalt to be about 300 feet thick. As at the other two wells, the upper part of the section, here only 120 feet thick, consists exclusively of type 2 rocks, mostly 2*a* with only minor amounts of type 2*c*. The number of flows is indeterminate.

Below this, types 1 and 2 seem to alternate. Types 1*a*, 1*b*, 1*c*, and 2*a* occur. Five rocks are recognizable and at least four flows are present.

CORRELATION OF THE BASALTS

The larger features of the basalts, previously described, are the same at all occurrences. In the eastern occurrences, from Stony Ridge to Kanaka Peak, where the largest interval between outcrops is no more than 6 miles, no one would hesitate to conclude on the grounds of megascopic features that all are of the same sequence of flows. This was the conclusion of Turner, and he also correlated the basalts at Walker Plain, Oroville Table Mountain, and Chico Creek with the

others. On the grounds of megascopic character this is completely justified, for there are no points of differences that can outweigh the remarkable similarities. On the same grounds, one would also conclude that the rocks at Orland Buttes and Putnam Peak are the same but for the distance between them. On the surface it is 30 miles from Orland Buttes to Chico Creek, and 40 miles to Oroville Table Mountain. It is about 78 miles from Oroville Table Mountain to Putnam Peak. Furthermore, there are the tentatively expressed views that the basalts at Oroville, Orland Buttes, and Putnam Peak are Pliocene or Pleistocene in age. Considering known occurrences of the basalt in the subsurface, the largest gap, as it appears at present between Oroville and Orland Buttes, is only about 18 miles and the largest gap between Oroville and Putnam is 40 miles.

The megascopic aspects of the rocks strongly indicate that all known occurrences are the same. Yet, it is well known that basalts of identical appearance occur in widely different geologic ages, and while megascopic features reflect fundamental properties, they are still superficial. On the other hand, some of the features of these rocks are not common to basalts elsewhere. Such are the absence of scoria and breccia between flows, the general scarcity of vesicles and amygdules, and the peculiar joint pattern that divides the rock into crude small columns, and at the same time, into equidemensional polyhedrons.

In their microscopical properties the rocks are unusual in several respects. Such are the peculiar clustering of the microlites of augite and olivine, but not of feldspar and magnetite, the presence in type 2 rocks of a second generation of augite in the mesostasis, which is probably titaniferous, and the presence in type 1 rocks of late apatite in the glass. I have not encountered similar rocks elsewhere in this vicinity.

The differences between type 1 and type 2 rocks might be considered of sufficient magnitude to indicate that two quite different rocks are present, yet there are overlaps in properties. Clustering is almost but not quite universal in type 2 rocks, and it does occur in type 1 rocks. A few rocks are transitional in that they contain glass, apatite, augite, and dusty magnetite in the mesostasis.

There is also complete geographic overlap of the type 1 and type 2 rocks. Both are at the extremes of the basalt and at intermediate points such as Red Clover Creek (Stony Ridge has not been studied in thin-section, and Squaw Valley is represented by only two samples), both north and south of Little Grizzly Creek, Lee Summit, Onion Valley, South Fork of Feather River, Lumpkin Ridge, Oroville Table Mountain, Orland Buttes, Putnam Peak, and in the three well sections.

The range of occurrence of the various types is as follows:

Type 1*a:* Squaw Valley to Putnam Peak and Orland Buttes.
Type 1*b:* Red Clover Creek to Parrott, B-2 and B-8.
Type 1*c:* Squaw Valley to Parrott, B-2.
Type 2*a:* Red Clover Creek to Putnam Peak and Orland Buttes.
Type 2*b:* Red Clover Creek to Parrott, B-8.
Type 2*c:* Red Clover Creek to Parrott, B-2 and B-8.
Type 2*d:* Rattlesnake Creek (near Lee Summit) to Safford No. 1.

There is complete geographic overlap not only of the main types 1 and 2, but there is nearly complete overlap of the subtypes.

Vertical sections also show some consistency. At Orland Buttes (2 flows), Putnam Peak (2 flows), in the three wells, and at Oroville Table Mountain, the lower flows are type 1 or types 1 and 2 mixed, whereas the higher flows are all of type 2. Farther east, type 1 and type 2 flows are intermixed, with a great dominance of type 2.

Thus there are many aspects of these rocks, both megascopic and microscopic, that are unusual among basalts. Both the characteristic megascopic and microscopic features are present throughout the range of occurrence of the basalt horizontally and vertically wherever a considerable section was available and has been studied. Hence it is concluded that all are a part of a once-continuous series of flows of the same geologic age. It seems improbable almost to the degree of impossibility that there could be represented here two series of lavas with identical properties but of different ages. The basalts in the subsurface of the Sacramento Valley are included on the grounds of identity of their microscopic properties, and of the megascopic appearance of the available chips, with the rocks in outcrops.

CONDITIONS OF ORIGIN

The Lovejoy formation extends over a roughly triangular area the three corners of which are near Honey Lake, Orland Buttes, and Putnam Peak. It is 104 miles from the Stony Ridge occurrence near Honey Lake to Orland Buttes, and 147 miles to Putnam Peak. It is 90 miles from Orland Buttes to Putnam Peak.

It is not known for sure that basalt ever covered all of this area, nor is it known that the basalt was not more extensive than is indicated by its present limits of occurrence. In fact, the abrupt termination of the estimated 600-foot-thick section on the face of the Honey Lake fault scarp indicates that the basalt once extended farther east.

The basalt occupies a broad stream-cut valley from Honey Lake to Oroville which may be taken to indicate that the lava did not extend much farther north and south than it does now.

Interbedded gravels show that at remarkably few places did streams flow on the surfaces of lava flows. Cobbles of granitic rocks that are foreign to the region show, however, that the streams flowed from the east or northeast, as did the Middle Eocene streams that deposited the Auriferous gravels (Durrell, 1959). However, the basalts did not occupy the same valley as that in which these Auriferous gravels were deposited; the latter trended more to the south, and is parallel to the former only in the extreme northeastern region.

No evidence has been found in the basalt itself which would indicate direction of flow. No dikes, plugs, or other intrusions that could be the source of the lava have been found by anyone. The sill of olivine diabase at the top of the section north of Red Clover Creek may be of the younger series of olivine basalt (Warner basalt).

It has not been possible to correlate individual flows from one area of occurrence to another, although this might prove possible through more detailed work.

That the magma was a highly fluid one is indicated by the lack of scoria and breccia, and by the holocrystalline character of most of the lava (type 2*a*).

The Lovejoy is bounded below and above by unconformities. Subsequent formations in the east are composed of material that traveled from east to west. Such are the data that bear on the question of origin.

The obvious conclusion to draw is that the basalt originated east of its easternmost occurrence, flowed southwesterly to the Sacramento Valley, and spread out there over relatively flat ground. This is consistent with the known westward slope of the region both before and after the deposition of the Lovejoy, and with an eastern source of pebbles in the interbedded gravels. It is consistent with an absence of known sources within the region. Inconsistent with this concept is the fact that sequences of flows do not correlate across short gaps.

It may also be objected that magma cannot flow so far. Some evidence has been offered that the magma was a very fluid one, and beyond this one can only appeal to other examples. The great Laki eruption in Iceland in 1783 proceeded from a fissure 20 miles long. The lava flowed for 40 miles on one side of the fissure and 28 miles on the other. The lava covered 218 square miles, and has a volume of three cubic miles (Tyrrell, 1931). The Frambruni flow, of prehistoric date in Iceland, flowed 69 miles, and the Veidivatnahraun flow also prehistoric, in Iceland, flowed 93 miles (Daly, 1933). Tyrrell (1931) also reports a flow in Iceland that traveled 14 miles on a slope of only 57 feet. Waters (in Poldervaart, 1955, p. 708), in describing the Columbia lavas of northwestern United States, says that "one flow, exposed in the deep canyons of northeastern Oregon, and adjacent parts of Idaho and Washington, is 380–400 feet thick and has been traced for more than 120 miles north-south, and 50 miles east-west; it disappears on all sides beneath younger flows." The distance of 147 miles between Stony Ridge and Putnam Peak does not, therefore, seem an impossible one for the lava to have flowed. The concept of a source east of the Honey Lake fault scarp is therefore presented on a provisional basis.

AGE OF THE LOVEJOY FORMATION

The Lovejoy formation as represented in the mountains east of Oroville was placed in the Neocene by Turner (1897, 1898), and was thought to be younger than the rhyolite, but older than the pyroxene andesite. At Oroville Table Mountain, Lindgren (1911) placed it in the Miocene, along with the Ione formation. Later, the basalt at Oroville Table Mountain (Creely, 1954), along with that beneath the Sacramento Valley (Cross, n.d.), was considered tentatively to be Pliocene, for the reason that there is supposed to be andesite tuff below it which has been provisionally correlated with the Mehrten formation (Creely, 1954). It has been shown above that there is no andesite tuff or breccia below the basalt at Oroville Table Mountain, although there are cobbles of hornblende andesite in the upper part of the underlying Ione, and in the upper part of the Auriferous gravels, as noted by Turner as early as 1896. No fossils have been found between the lavas of the Lovejoy formation, and it has not been shown that rocks of Pliocene age occur interbedded with or beneath the basalt. Regardless of the nature of its occurrence, the hornblende andesite at Oroville Table Mountain has no validity as an indicator of age because hornblende andesites megascopically indistinguishable from those of Pliocene age occur also in the Miocene, the Oligocene, and the Eocene.

The earliest demonstration of the early age of hornblende andesite in the Sierra Nevada is in the paper by Clark and Anderson (1938) on the Wheatland formation which occurs about 40 miles southeast of Oroville. The Wheatland contains marine invertebrates of Oligocene age, as shown by Clark, and the same conglomerates that contain the fossils also contain cobbles of hornblende andesite megascopically indistinguishable from those of Miocene and Pliocene age elsewhere in the Sierra Nevada. Nearby the Reeds Creek andesite described by the authors in the same paper contains mudflow breccias with hornblende andesite. If the Reeds Creek is not also Oligocene it is certainly older than the associated rhyolite tuff, which in turn is clearly older than the Mehrten formation.

The Montgomery Creek beds of Middle Eocene age (Anderson and Russell, 1939) near the town of Montgomery Creek, 95 miles north of Oroville, likewise contain an abundance of hornblende andesite pebbles and cobbles, which can be seen in road cuts along the new highway which are probably in sec. 31, T.35N., R.1E. (Burney quadrangle), and along the Cove road in secs. 24 and 25, T.35N., R.1W. (Burney quadrangle).

Hornblende andesite cobbles are also present in abundance in the upper part of the Auriferous gravels at Moonlight Valley about 60 miles northeast of Oroville, at the fossil locality whereby the rocks are dated as Eocene (Diller, 1908, near the center of sec. 36, T.28N., R.10E.). The locality has been recently visited by me in the company of D.I. Axelrod who has confirmed the Eocene age on the basis of fossils collected at that time. At another occurrence, a few miles northeast of Moonlight, in sec. 4, T.28N., R.11E., and vicinity, Susanville quadrangle, gravels of Eocene age (Diller, 1908) are composed almost exclusively of andesite cobbles with a sandy matrix of andesitic character.

In the Blairsden quadrangle (Durrell, 1959) hornblende andesite mudflow breccias occur in three formations, all younger than the Lovejoy. The oldest, the Ingalls formation, is possibly Oligocene, and equivalent to the Wheatland or Reeds Creek formations, and to the Alta andesite of the Virginia City District, Nevada (Gianella, 1936; Axelrod, 1949), which also contains hornblende andesite. The Ingalls is overlain unconformably by the Delleker formation, of biotite rhyolite tuff, which, by a long-distance correlation, is thought to be Middle Miocene. The Bonta formation, resting unconformably on the Delleker, contains hornblende andesite in abundance. It is Upper Miocene in age, as it contains the Mohawk flora at the base (Axelrod, 1957). The Bonta in turn is overlain unconformably by the Penman formation, dominantly of hornblende andesite, and which is probably equivalent to the Mehrten formation of the central Sierra Nevada.

In view of the demonstrable wide distribution in time and space of hornblende andesite in northeastern California, it should be apparent that whatever the character of the andesite beneath the basalt at Oroville Table Mountain, it has no age significance. The lower limit of age is therefore not determined by the occurrence of hornblende andesite beneath the basalt of Table Mountain, but by the age of the youngest dated rocks beneath it. In the Blairsden quadrangle, at Oroville Table Mountain, and at numerous places in between, the basalt rests on the Auriferous gravels that are Middle Eocene (MacGinitie, 1941). In the Sacramento Valley the basalt rests on the Middle Eocene Capay formation (Cross,

n.d.), and at Putnam Peak, it rests on the Upper Eocene Markley formation (Weaver, 1949).

The upper limit of age is best established by relationships in the Sierra Nevada. At Red Clover Creek and elsewhere in the Blairsden quadrangle, the Lovejoy is overlain by the Ingalls formation (Durrell, 1959), which is thought to be Oligocene in age (see above). This dating is somewhat tenuous, however, and better evidence is obtained at La Porte.

The town of La Porte is near the west edge of the Downieville quadrangle (Turner, 1897). One mile north and a little west of town in the northeast quarter of sec. 8, T.21N., R.9E., in the Upper Dutch Diggings (see La Porte, 1:24,000, quadrangle), is the tuff bed in which the well-known La Porte flora occurs (Potbury, 1935). The leaf-bearing tuff is at the top of the cliff on the west side of the diggings. It overlies carbonaceous lacustrine clay and arkose which in turn rests on Auriferous gravels. The tuff is in turn overlain by andesite mudflow breccia, which is probably equivalent to the Penman formation of the Blairsden quadrangle. At the base of the cliff lie two boulders of Lovejoy basalt, each about 15 feet in diameter, and numerous small, slightly rounded blocks of the same rock are strewn over the lower half of the cliff. The cliff is armored with clay that has washed down the slope, but by digging through this armor, the basalt blocks are revealed in place in the lacustrine clays. Thus the Lovejoy basalt is reworked into beds older than the leaf-bearing tuff, which according to Potbury is Eocene or lowest Oligocene, and, according to MacGinitie (personal communication), who is presently restudying the Early Tertiary floras of the Sierra Nevada, is Upper Eocene or Lower Oligocene.

Small well-rounded pebbles of Lovejoy are in a thin conglomerate at the base of the andesite above the tuff, but no other blocks or cobbles of Lovejoy occur above the pit wall. Consequently there can be no doubt as to the stratigraphic position of the Lovejoy blocks below. The nearest possible source of the Lovejoy blocks is the eastern end of Mooreville Ridge, which is 1 mile northwest.

Hence the Lovejoy is older than Upper Eocene or Lower Oligocene, and younger than the Middle Eocene Capay formation. If the Putnam Peak basalt is properly correlated with the Lovejoy, the latter is further restricted as younger than the Upper Eocene Markley formation. It is therefore very high in the Eocene, or possibly lowest Oligocene.

LITERATURE CITED

ALLEN, V. T.

1929. The Ione formation of California. Univ. Calif., Dept. Geol. Sci., Bull., vol. 18, pp. 347–448.

ANDERSON, C. A., and R. D. RUSSELL

1939. Tertiary formations of northern Sacramento Valley, California. Calif. Jour. Mines and Geol., vol. 35, pp. 219–253.

AXELROD, D. I.

1949. Eocene and Oligocene formations in the western Great Basin (Abst.). Geol. Soc. Am., Bull., vol. 60, pp. 1935–1936.

1957. Late Tertiary floras and the Sierra Nevada uplift. Geol. Soc. Am., Bull., vol. 68, pp. 19–46.

CLARK, B. L., and C. A. ANDERSON.

1938. Wheatland formation and its relation to Early Tertiary andesites in the Sierra Nevada. Geol. Soc. Am., Bull., vol. 49, pp. 931–956.

CREELY, R. S.

1954. Geology of the Oroville quadrangle. Unpublished Ph.D. thesis, Univ. of Calif., Berkeley.

CROSS, C. M., *et al.*

(n.d.). Correlation section, northern Sacramento Valley. Subcommittee on Mesozoic, of the geologic names and correlation committee of the Amer. Assoc. Pet. Geol. C. M. Cross, ch. Publ. by Pac. Sect. Amer. Assoc. Pet. Geol.

DALY, R. A.

1933. Igneous rocks and the depths of the earth. New York: McGraw-Hill.

DICKERSON, R. E.

1916. Stratigraphy and fauna of the Tejon Eocene of California. Univ. Calif., Dept. Geol. Sci., Bull., vol. 9, pp. 363–524.

DILLER, J. S.

1908. Geology of the Taylorsville region, California. U.S. Geol. Surv. Bull., vol. 353, pp. 1–128.

DURRELL, C.

1959. Tertiary stratigraphy of the Blairsden quadrangle, Plumas County, California. Univ. Calif. Publ. Geol. Sci., vol. 34, no. 3, pp. 161–192.

GIANELLA, V. P.

1936. Geology of the Silver City district and the southern portion of the Comstock Lode, Nevada. Univ. Nev. Bull., vol. 30, 105 pp.

LINDGREN, W.

1911. The Tertiary gravels of the Sierra Nevada of California. U.S. Geol. Surv., Prof. Paper 73, pp. 1–226.

POLDERVAART, A.

1955. Crust of the earth (a symposium). Geol. Soc. Am., Spec. Paper 62, pp. 703–722.

POTBURY, S. S.

1935. The La Porte flora of Plumas County, California. Carnegie Inst. Wash., Publ. 465, pp. 31–82.

MACGINITIE, H. D.

1941. A Middle Eocene flora from the central Sierra Nevada. Carnegie Inst. Wash., Publ. 534, pp. 178.

TURNER, H. W.

1895. The rocks of the Sierra Nevada: U.S. Geol. Surv., 14th Ann. Rep., pp. 435–495.

1896. Further contributions to the geology of the Sierra Nevada. U.S. Geol. Surv., 17th Ann. Rep., Pt. I., pp. 521–1076.

1897. The Downieville quadrangle. U.S. Geol. Surv., Geol. Atlas, Folio 37.
1898. The Bidwell Bar quadrangle. U.S. Geol. Surv., Geol. Atlas, Folio 43.

TYRRELL, G. S.
1931. Volcanoes. London: Thornton–Butterworth. 250 pp.

WEAVER, C. E.
1949. Geology of the Coast Ranges immediately north of the San Francisco Bay Region, California. Geol. Soc. Am., Mem. 35, pp. 1–242.

a. Type section of the Lovejoy formation in the Red Creek area, secs. 30 and 31 of T.25N., R.13E., Blairsden quadrangle. Shows a typical outcrop with cliffs and benches, talus and sparse vegetation.

b. Close-up of basalt of Lovejoy formation to show the typical joints, and irregular small columns. Sec. 30, T.25N., R.13E., Blairsden quadrangle.